# Prospective randomized comparison of high-pitch CT at 80 kVp under free breathing with standard-pitch CT at 100 kVp under breath-hold for detection of pulmonary embolism

Martini, K ; Meier, A ; Higashigaito, K ; Saltybaeva, N ; Alkadhi, H ; Frauenfelder, T

Abstract: RATIONALE AND OBJECTIVES To prospectively compare high-pitch computed tomography (HPCT) under free breathing (FB) with standard-pitch CT (SPCT) under breath-hold (BH) for detection of pulmonary embolism (PE). MATERIALS AND METHODS One hundred consecutive patients (47 females; mean age 58.7 ± 16.6) randomly underwent HPCT-FB (n = 50) or SPCT-BH (n = 50). Radiation doses were documented. One reader measured pulmonary artery attenuation and noise; mean signal-to-noise ratio (SNR) was calculated. Two readers assessed image quality, diagnostic confidence for detection of PE, motion artifacts, assessability of anatomical structures, and presence of transient interruption of contrast as sign of Valsalva maneuver. Inter-reader agreement was calculated. RESULTS Radiation dose was significantly lower in HPCT compared to SPCT (2.68 ± 0.60 mGy vs 6.01 ± 2.26 mGy; P < .001). Mean pulmonary artery attenuation and image noise were significantly higher in HPCT (attenuation: 479 Hounsfield unit (HU) vs 343HU; P < .001; noise: 16 HU vs 10 HU; P < .001) whereas SNR was similar between groups (34 HU vs 38 HU; P = .258). HPCT had significantly higher diagnostic confidence for PE detection (P = .048), less cardiac and breathing artifacts (P < .001), better assessability of anatomical structures, and fewer cases of transient interruption of contrast (P < .001) compared to the SPCT. CONCLUSIONS HPCT-FB allows for a significant reduction of breathing and motion artifacts compared to SPCT-BH. Diagnostic confidence, assessability of vascular and bronchial structures, as well as SNR are maintained.

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Original Investigation

# Prospective Randomized Comparison of High-pitch CT at 80 kVp Under Free Breathing with Standard-pitch CT at 100 kVp Under Breath-Hold for Detection of Pulmonary Embolism

K. Martini, MD, A. Meier, MD, K. Higashigaito, MD, N. Saltybaeva, PhD, H. Alkadhi, MD, T. Frauenfelder, PD, MD

**Rationale and Objectives:** To prospectively compare high-pitch computed tomography (HPCT) under free breathing (FB) with standard-pitch CT (SPCT) under breath-hold (BH) for detection of pulmonary embolism (PE).

**Materials and Methods:** One hundred consecutive patients (47 females; mean age 58.7 ± 16.6) randomly underwent HPCT-FB (n = 50) or SPCT-BH (n = 50). Radiation doses were documented. One reader measured pulmonary artery attenuation and noise; mean signal-to-noise ratio (SNR) was calculated. Two readers assessed image quality, diagnostic confidence for detection of PE, motion artifacts, assessability of anatomical structures, and presence of transient interruption of contrast as sign of Valsalva maneuver. Inter-reader agreement was calculated.

**Results:** Radiation dose was significantly lower in HPCT compared to SPCT (2.68 ± 0.60 mGy vs 6.01 ± 2.26 mGy; $P < .001$). Mean pulmonary artery attenuation and image noise were significantly higher in HPCT (attenuation: 479 Hounsfield unit (HU) vs 343HU; $P < .001$; noise: 16 HU vs 10 HU; $P < .001$) whereas SNR was similar between groups (34 HU vs 38 HU; $P = .258$). HPCT had significantly higher diagnostic confidence for PE detection ($P = .048$), less cardiac and breathing artifacts ($P < .001$), better assessability of anatomical structures, and fewer cases of transient interruption of contrast ($P < .001$) compared to the SPCT.

**Conclusions:** HPCT-FB allows for a significant reduction of breathing and motion artifacts compared to SPCT-BH. Diagnostic confidence, assessability of vascular and bronchial structures, as well as SNR are maintained.

**Key Words:** Pulmonary embolism; multidetector computed tomography; Valsalva maneuver; artifacts; imaging.



## INTRODUCTION

The annual incidence of venous thromboembolism is reported to be between 20 and 70 cases per 100,000 (1,2). One-third of those patients will have acute pulmonary embolism (PE), whereas two-thirds will remain isolated deep vein thrombosis (3). The current approach to patients with suspected PE is based on a clinical adjudication of patients into a high-risk (>15%) and a nonhigh-risk group of early PE-related death (4). Computed tomography (CT) angiography is the first-choice imaging modality in high risk patients suspected of PE (1).

Conventional CT angiography protocols require scans under breath-hold (BH). Breath-holding is beneficial for the reduction of motion artifacts and for image quality, but has also negative aspects as follows:

1. PE patients present with dyspnea, and have therefore difficulties to hold their breath. In some cases, patient compliance and patient status do not allow for breath-holding.
2. BH can have hemodynamic effects that may result in high attenuation of the aorta, with lower pulmonary artery attenuation (5).

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From the Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, University of Zurich, Rämistrasse 100, CH-8091 Zürich, Switzerland. Received May 25, 2016; revised July 18, 2016; accepted July 19, 2016. **Address correspondence to:** K.M. e-mail: Thomas.frauenfelder@usz.ch


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3. Unintentionally performed Valsalva maneuver may suddenly increase intrathoracic pressure during deep inspiration, forcing blood out of the pulmonary circulation into the left atrium and resulting in suboptimal contrast in the pulmonary arteries (6).

Because of the negative effects of breath-holding, it would be desirable to have CT PE protocols that can be performed under free breathing (FB).

CT scans under FB can only be performed if image acquisition is fast to avoid breathing movements being depicted on the acquired image. One option to reduce scan time is the increase of pitch mode. In that way, it is possible to scan patients under FB, while avoiding undesired hemodynamic effects of BH and reducing motion artifacts resulting from FB. Bauer et al. (7) showed that CT for the detection of PE can be accomplished using high-pitch mode (HPM) at low radiation dose, with maintaining diagnostic image quality even without suspended respiration. However, Bauer et al. did not have a control group in his study.

With an increase of pitch and decrease of rotation time, we aimed to lower the incidence of motion artifacts and suboptimal contrast in the pulmonary arteries caused by Valsalva maneuver.

Therefore, the purpose of our study was to investigate prospectively and randomized diagnostic value of high-pitch CT (HPCT) under FB compared to standard-pitch CT (SPCT) under BH for the detection of PE.

## MATERIALS AND METHODS

### Patient Population

The local ethics committee approved the study and written informed consent was obtained from all patients. Between July 2014 and June 2015, 108 consecutive patients who were referred to our hospital with suspicion of PE were prospectively enrolled in the study. Exclusion criteria were a body mass index (BMI) > 30 kg/m$^2$ (n = 4), renal failure, and hypersensitivity to iodinated contrast media (n = 4). Thus, the final cohort constituted 100 patients (47 females, 53 males; mean age 58.74 years ±16.6) who underwent 1:1 randomization into 2 groups: 50 patients were scanned under inspiratory BH and with SPCT (SPCT group), and 50 patients were scanned under FB with HPCT (HPCT group). Patients' age, sex, weight, height, and BMI were recorded (Table 1). A 30-day clinical follow-up was performed to detect any events related to PE (ie, repeated CT evaluation for suspected PE, hospitalization related to PE, death related to PE).

### CT Protocols

Single-energy CT was performed in all patients on a third-generation dual-source CT scanner (SOMATOM Force; Siemens Healthcare, Forchheim, Germany) equipped with an integrated high-resolution detector (Stellar Technology; Siemens Siemens Healthcare). Scanning parameters were as follows:

1. SPCT-BH: SPCT was performed at 100 kVp with quality reference current-time product of 80 mAs, a pitch of 1.2, gantry rotation time of 0.5 second, and slice acquisition of 192 × 0.6 mm by means of a z-flying focal spot. The onsite CT technician detailed the breathing instructions to the patient.
2. HPCT-FB: HPCT was performed at 80 kVp with 150 mAs quality reference, a pitch of 3, gantry rotation time 0.25 second, and slice acquisition 192 × 0.6 mm. The patients were instructed to breathe normally during the scans.

A double-syringe power injector (CT Exprés, Bracco, formerly Swiss Medical Care, Switzerland) infused intravenous (IV) contrast via an antecubital, subclavian, or internal jugular venous access. IV contrast (80 mL; iopromide, Ultravist, 300 mg J/mL, Bayer HealthCare, Germany) was followed by 50 mL saline bolus, both at a flow rate of 4 mL/s. Bolus tracking was performed with a threshold at 100 Hounsfield unit (HU) (at 100 kVp) in the main pulmonary artery, with a trigger delay of 10 seconds.

All images were reconstructed with advanced modeled iterative reconstruction (ADMIRE, Siemens Healthcare) at a strength level of 3, using a slice thickness of 1.5 mm, an increment of 1 mm, and a tissue convolution kernel (Bl34). The image matrix was 512 × 512 pixels.

Subsequent analyses were performed using the picture archiving and communication system of our hospital (Impax, Version 6.5.5.1033; Agfa-Gevaert, Mortsel, Belgium) on a high-definition liquid crystal display monitor (BARCO; Medical Imaging Systems, Kortrijk, Belgium).

**TABLE 1. Patient Characteristics**

| | Total (n = 100) | SPCT-BH (n = 50) | HPCT-FB (n = 50) | *P* Value |
|---|---|---|---|---|
| *Female : Male* | 47:53 | 20:30 | 27:23 | — |
| *Mean age (j)* | 58.74 (±16.9) | 57.22 (±16.4) | 60.26 | .317 |
| *Mean height (cm)* | 170 (±0.1) | 172 (±0.1) | 1.68 | .083 |
| *Mean weight (kg)* | 70.33 (±13.3) | 72.56 (±14.7) | 68.1 | .140 |
| *Mean BMI (kg/m$^2$)* | 24.17 (±3.5) | 24.44 (±3.6) | 23.89 | .248 |

BMI, body mass index; HPCT-FB, high-pitch computed tomography under free breathing; SPCT-BH, standard-pitch computed tomography under breath-hold.

### Radiation Dose

The volume CT dose index ($CTDI_{vol}$) and the dose-length product (DLP) were obtained from the electronically logged patient protocol of each scan. The effective dose of chest CT was calculated by multiplying the DLP by a region-specific conversion coefficient $E_{DLP}$ of 0.014 mSv/mGy × cm (8). Anteroposterior (AP) and lateral (LAT) chest diameters were measured. Based on the effective diameter of the chest (effective diameter = $\sqrt{(AP \times LAT)}$), size-specific dose estimates (SSDEs) were calculated using the size-specific conversion factor $f_{size}$ according to the AAPM Report 204 ($SSDE = f_{size} \times CTDI_{vol}$) (9).

### Quantitative Analysis

Image noise and pulmonary artery attenuation were measured by 1 blinded reader (KM, resident radiologist with 2 years of experience), who was not involved in subjective image quality grading. The region of interest (ROI) size was fixed at 50 $mm^2$. For noise measurements, a circular ROI was placed in the subcutaneous fat in the chest wall, whereas for pulmonary artery attenuation measurements, ROI was placed in the pulmonary truncus. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) values were calculated.

### Qualitative Analysis

The images were presented to 2 independent readers (KH and AM, resident radiologists, with 4 and 5 years of experience, respectively) blinded to the clinical information and to the protocol and breathing technique used. A total of 100 datasets were reviewed by both readers.

Readers were allowed to modify the window width and level after the initial presentation with a mediastinal window (window level 50 HU; width 350 HU). Both readers rated the overall image quality on a 5-point Likert scale as previously shown (10) (1 = nondiagnostic image quality, strong artifacts; 2 = severe blurring with uncertain evaluation; 3 = moderate blurring with restricted assessment; 4 = slight blurring with unrestricted diagnostic image assessment, 5 = excellent image quality, no artifacts). An image quality from 3 to 5 was considered as diagnostic. The same 2 readers also independently assessed the images for the presence of PE and assigned confidence levels on a 3-point Likert scale (1 = <70% sure, high possibility of false positive or false negative results; 2 = 70%–90% sure, intermediate diagnostic confidence, false positive or false negative results; 3 = >90% sure, no doubt for finding). Further, readers had to assess the presence of motion artifacts, such as body movement or breathing artifacts (yes or no), presence of pulsation artifacts of the heart (yes or no), and until which level bronchial structures were assessable (main bronchi, lobar bronchi, segmental bronchi, subsegmental bronchi). Further, readers assessed visualization of cardiac structures (septum, chambers, morphology overall) and vascular structures (upper field, intermediate field, and basal field) on a 4-point Likert scale (1 = nondiagnostic, strong artifacts; 2 = severe blurring with restricted assessment; 3 = good, unrestricted diagnostic image assessment; 4 = excellent assessment, no artifacts).

Additionally, images were evaluated for the presence of Valsalva maneuver (yes or no), evaluating the presence of transient interruption of contrast medium.

Images were assessed at a random order over a time period of 3 months.

### Statistical Analysis

Statistical analyses were conducted using commercially available software (SPSS, release 21.0; SPSS, Chicago, IL). Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were expressed as frequencies or percentages. Detection rate of PE was calculated for each protocol.

Cohen's kappa (κ) was used to assess inter-reader agreement for subjective image quality. Κ-results were stratified qualitatively by score (slight agreement, 0.01–0.20; fair agreement, 0.21–0.40; moderate agreement, 0.41–0.60; good agreement, 0.61–0.80; excellent agreement, 0.81–0.99 (11). Kolmogorov-Smirnov test was used to test for normality of the distribution. Friedman analysis of variance was used to assess image noise, pulmonary artery attenuation, and SNR of the scans for significant differences among the different tube current levels. A two-sided $P$ value below .05 was considered to indicate statistical significance.

## RESULTS

### Radiation Dose

$CTDI_{vol}$ as well as SSDE were significantly lower in the HPCT group than in the SPCT group ($CTDI_{vol}$: 2.68 mGy ± 0.60 vs 6.01 mGy ± 2.26; $P < .001$) (Table 2).

### Quantitative Analysis

Mean pulmonary artery attenuation was significantly higher in the HPCT-protocol compared to the SPCT (479 HU ± 154 vs 342 ± 112; $P < .001$). Mean attenuation of the subcutaneous fat layer was significantly lower in the HPCT

**TABLE 2. Radiation Dose**

| | Total (n = 100) | SPCT-BH (n = 50) | HPCT-FB (n = 50) | *P* Value |
|---|---|---|---|---|
| *DLP (mGy × cm)* | 160.17 | 223.85 | 96.49 | <.001 |
| *CTDI (mGy)* | 4.35 | 6.01 | 2.68 | <.001 |
| *SSDE (mGy)* | 5.39 | 7.41 | 3.38 | <.001 |

CTDI, computed tomography dose index; DLP, dose-length product; HPCT-FB, high-pitch computed tomography under free breathing; SPCT-BH, standard-pitch computed tomography under breath-hold; SSDE, size-specific dose estimate.

protocol compared to the SPCT (−121 HU ± 12 vs −65 ± 97; $P < .001$). Image noise was significantly higher in the HPCT compared to the SPCT protocol (16 HU ± 5.23 vs 10 HU ± 2.49, $P < .001$). SNR was not significantly different in both protocols (HPCT 34 vs 38; $P = .258$) (Table 3). CNR is significantly higher than the SPCT compared to the HPCT protocol in both protocols (41 vs 28; $P < .001$) (Table 3).

**TABLE 3. Attenuation and Noise**

| | Total (n = 100) | SPCT-BH (n = 50) | HPCT-FB (n = 50) | *P* Value |
|---|---|---|---|---|
| *Mean attenuation PA* | 410.67 | 342.45 | 478.92 | <.001 |
| *Mean attenuation subcutaneous fat* | −77 | -65.33 | -121.33 | <.001 |
| *Noise* | 12.76 | 9.59 | 15.94 | <.001 |
| *SNR* | 36.06 | 38.05 | 34.07 | .258 |
| *CNR* | 33.30 | 40.60 | 28.01 | <.001 |

CNR, contrast-to-noise ratio; HPCT-FB, high-pitch computed tomography under free breathing; PA, pulmonary artery; SNR, signal-to-noise ratio; SPCT-BH, standard-pitch computed tomography under breath-hold.

## Qualitative Analysis

All images in both groups were of diagnostic image quality for PE evaluation ($P > .05$). Whereas in the SPCT 8 patients were diagnosed with PE, in the HPCT 4 patients were diagnosed with PE. Diagnostic confidence was scored significantly higher for HPCT compared to SPCT (mean score = 2.89 vs 2.80 respectively; $P = .048$) (Fig 1).

During the 30-day follow-up period, 6 of the 100 included patients underwent repeated chest CT: 3 with suspected PE (all 3 out of the former SPCT group), 3 with suspected pulmonary infection (1 patient from the HPCT group, 2 patients from the SPCT group). In 1 of the 3 patients suspected with PE (and originally from the SPCT group), the already previously diagnosed PE was confirmed, whereas the other 2 patients continued to have a negative result for PE as they did already in the previous evaluation. Additionally, the patients' clinical record showed no further event related to PE.

There were significantly more movement and breathing artifacts and significantly more heart pulsation artifacts in images obtained with the SPCT compared to the HPCT (70% vs 30% and 95% vs 18%, respectively; $P < .001$) (Fig 2).

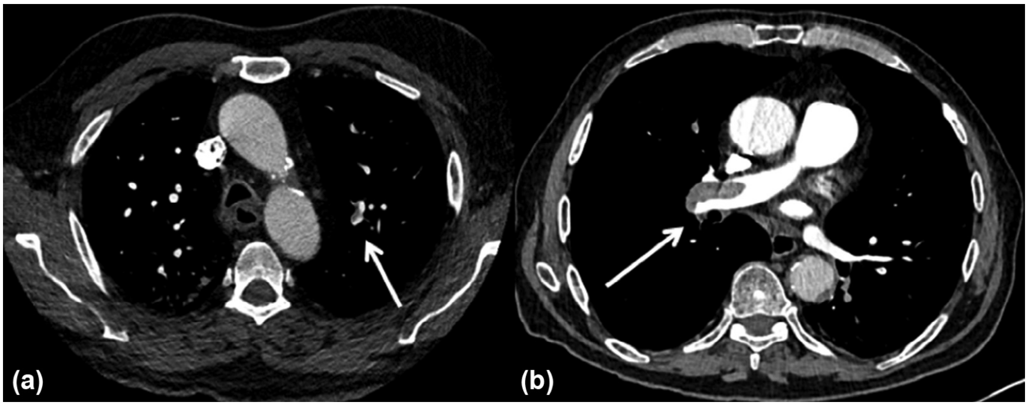


**Figure 1.** Patient with pulmonary embolism **(a)** with the standard pitch computed tomography under breath-hold protocol and **(b)** with the high-pitch computed tomography under free breathing protocol.

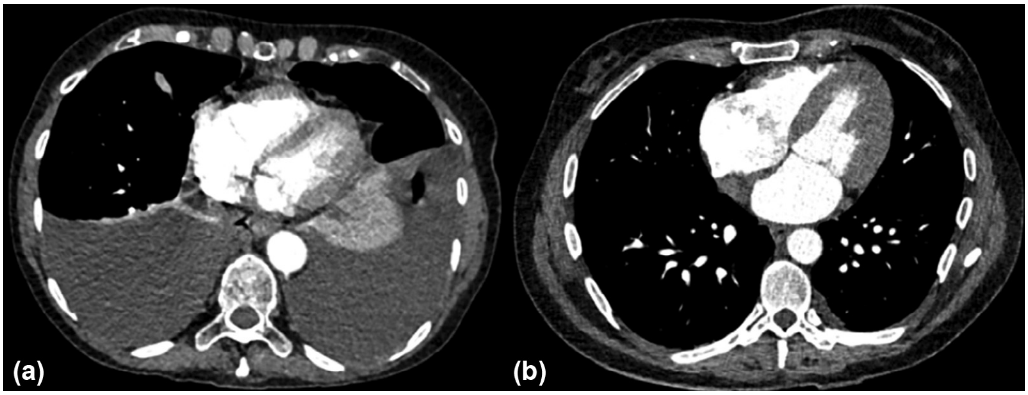


**Figure 2.** The computed tomography (CT) image in **(a)** (acquired with the standard pitch CT under breath-hold protocol) shows heart pulsation artifacts, whereas the CT in **(b)** (acquired with the high-pitch CT under free breathing protocol) is free of motion artifacts.

Assessment of cardiac structures was scored significantly higher in HPCT compared to SPCT (mean score = 3.69 vs 3.16, respectively; $P < .001$). Assessment of bronchial structures showed no significant difference throughout the protocols ($P > .05$).

Assessability of vascular structures in the upper field, intermediate field, as well as the lower field was not significantly different among the evaluated protocols ($P > .05$).

Assessment of Valsalva maneuver showed significantly more patients presenting interruption of contrast medium scanned with the SPCT under BH compared to patients scanned with the HPCT under FB (superior vena cava: 6 % vs 28%, right ventricle: 4 % vs 30 %; $P < .001$).

Detailed results for each reader are illustrated in Tables 4 and 5.

## DISCUSSION

Our prospective randomized study demonstrates that HPCT under FB showed significantly less breathing and cardiac motion artifacts compared to SPCT under BH. Diagnostic confidence and assessability of vascular and bronchial structures were maintained, whereas transient interruption of contrast was lower in the HPCT group. The image quality was diagnostic in all cases, regardless of which protocol was used.

Some authors evaluated the impact of high-pitch protocols on enhanced chest CT (7,12–15).

However, to our best knowledge this is the first randomized study with a large sample size comparing prospectively SPCT under BH to HPCT under FB without the use of electrocardiogram (ECG) triggering and employing most recent third-generation dual-source CT.

Patients with suspicion of PE often present with difficulties breathing or shortness of breath. This condition makes it difficult for them to follow BH instructions and therefore image acquisition often goes along with breathing artifacts.

Acquiring images at HPM, even if the patient was allowed to breath, resulted in less breathing artifacts, because the image acquisition was faster than the patient's breathing frequency. Additionally, HPM allowed also for a reduction of cardiac pulsation artifacts in a similar way. The reduction of cardiac motion artifacts allowed for a better visualization of cardiac structures such as the heart septum as well as heart morphology overall. This is important because right-to-left ventricle dilation can be used to evaluate risk of death in patients with PE and in hemodynamically stable patients (16,17).

There exist already some in vivo and ex vivo studies that evaluated the potential of HPM for compensation of motion artifacts with positive results (18–22). Baumueller et al. (22) investigated whether HPM for CT enables the diagnostic visualization of lung parenchyma under breathing and found that CT of the lung can be accomplished using HPM at low radiation dose, with maintaining diagnostic image quality even without suspended respiration. Other authors (10,18,19) evaluated HPM for the feasibility in coronary CT angiography and found that CT performed at HPM allows for coronary angiography with high pitch up to 70 bpm. In the above-listed studies, image acquisition was performed ECG-gated and did not test HPM for the detection of PE protocols. However, their findings could be used for the

**TABLE 4. Presence of Movement Artifacts and Valsalva Artifact**

| | SPCT-BH (n = 50) | | HPCT-FB (n = 50) | | |
|---|---|---|---|---|---|
| | R1 (%) | R2 (%) | R1 (%) | R2 (%) | *P* Value |
| *Breathing* | 94 | 70 | 36 | 42 | <.001 |
| *Heart pulsation* | 90 | 76 | 16 | 9 | <.001 |
| *Valsalva artifact* | 28 | 30 | 6 | 4 | <.001 |

HPCT-FB, high-pitch computed tomography under free breathing; R1, reader 1; R2, reader 2; SPCT-BH, standard-pitch computed tomography under breath-hold.
*P* value between the SPCT-BH and the HPCT-FB.

**TABLE 5. Assessability of Anatomical Structures**

| | Heart (Chambers, Septum, Morphology) | | | | Vascular Structures (Upper Field) | | | | Vascular Structures (Middle Field) | | | | Vascular Structures (Lower Field) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SPCT-BH (n = 50) | | HPCT-FB (n = 50) | | SPCT-BH (n = 50) | | HPCT-FB (n = 50) | | SPCT-BH (n = 50) | | HPCT-FB (n = 50) | | SPCT-BH (n = 50) | | HPCT-FB (n = 50) | |
| | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) | *R1* (%) | *R2* (%) |
| *Nondiagnostic* | *0* | *0* | *0* | *0* | *2* | *2* | *0* | *0* | *0* | *2* | *0* | *0* | *0* | *2* | *0* | *0* |
| *Restricted assessment* | *2* | *12* | *2* | *4* | *8* | *6* | *2* | *4* | *4* | *4* | *0* | *6* | *4* | *4* | *0* | *6* |
| *Good* | *80* | *60* | *22* | *28* | *30* | *32* | *20* | *22* | *22* | *30* | *14* | *16* | *20* | *30* | *26* | *20* |
| *Excellent* | *18* | *28* | *76* | *68* | *60* | *60* | *78* | *74* | *74* | *64* | *86* | *78* | *76* | *64* | *74* | *74* |

HPCT-FB, high-pitch computed tomography under free breathing; R1, reader 1; R2, reader 2; SPCT-BH, standard-pitch computed tomography under breath-hold.
*P* value between the SPCT-BH and the HPCT-FB.

implementation of HPM in non-ECG-triggered PE protocols (10,18,19,22).

There are other authors who evaluated HPM in PE protocols. For example, Bauer et al. (7) investigated pulmonary arterial enhancement, image noise, and artifacts related to breathing and heart motion in patients with suspected PE. He found that HPCT in freely breathing patients effectively produces images that are free of artifacts related to breathing and cardiac motion. Valsalva-related artifacts can be reduced using this technique (7). These findings are in line with our study.

Even though CNR is shown to be significantly higher in the SPCT protocol compared to the HPCT protocol, diagnostic image quality and diagnostic confidence were not different or even better in the HPCT protocol. We think that this accounts mainly to (1) the higher signal in the pulmonary arteries and (2) the reduction of motion artifacts. Li et al. (12) assessed image quality, radiation dose, and diagnostic accuracy of 70-kVp high-pitch computed tomography pulmonary angiography (CTPA) using 40 mL contrast agent and sinogram affirmed iterative reconstruction (SAFIRE) compared to 100-kVp CTPA using 60 mL contrast agent and filtered back projection. They found that 70-kVp high-pitch CTPA with reduced contrast media and SAFIRE provides comparable image quality and substantial radiation dose savings compared to a routine CTPA protocol (12).

In contrast to the above-mentioned studies (7,12), in our study scan time was not only reduced by increasing pitch, but also by the reduction of rotation time down to 0.25 second. This allowed for a further scan time reduction and resulted in a further reduction of radiation dose.

To keep image quality high despite the decreased scan time, different approaches were used: First, by acquiring the images using an integrated circuit detector (ie, the stellar detector); second, by using iterative reconstruction (ADMIRE) at the strength level 3; and third, by decreasing tube voltage from 100 kVp to 80 kVp. Decreasing tube voltage resulted in an increase of the iodine attenuation (23). Because of the higher iodine attenuation, we obtained a similar SNR in both groups, despite a higher noise in the HPCT-FB protocol. With the decrease in tube voltage, we aimed for a higher iodine attenuation in the pulmonary arteries and at the same time we were able to obtain an additional reduction in radiation dose. However, lowering tube voltage goes normally along with an increase in image noise. To keep image noise at an acceptable level, we increased tube current in the HPCT protocol.

Our study has some limitations: first, to guarantee optimal image quality and consecutively no disadvantage for any study participant, we did include only patients with a BMI $\leq 30\ \mathrm{kg/m^2}$. We were not sure if higher BMI values result in higher noise levels, impairing the evaluation for PE. Therefore, an extrapolation to obese patients is not possible. Second, we cannot be fully certain if patients were following breathing instructions thoroughly. Third, heart rate was not recorded during the scans. Therefore, cardiac motion could not be correlated with the heart rate. Fourth, the prevalence of PE in the HPCT-FB was lower compared to the HPCT-BH group, however, due to the positive image quality and diagnostic confidence rating assigned by both readers and the SNR that was not significantly different between the 2 protocols; this may be due to a real discrepancy of the presence of PE in the 2 study populations. Best would have been to scan all the included patients with both protocols to have a real standard of reference. However, this was not possible due to ethical considerations. Fifth, considering the huge differences in respiratory or cardiac motion artifacts and iodine attenuation, it is impossible to effectively blind readers. This introduces a potentially bias.

In conclusion, our study suggests that HPCT under FB allows for a significant reduction of breathing and cardiac motion artifacts compared to SPCT under BH, whereas diagnostic confidence and assessability of vascular and bronchial structures as well as SNR were maintained among protocols. Importantly, transient interruption of contrast indicating Valsalva maneuver was reduced in the HPCT group under FB.

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